US Army Corps of Engineers

Ice Engineering

U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

Safe Loads on Ice Sheets

Every winter, ice sheets that grow on lakes and rivers in northern states are used for ice roads, ice bridges, construction platforms, airstrips, and recreational activities. It becomes very important, therefore, to know when the ice is safe to use for these purposes. Figure 1 shows a tow truck and the pickup truck (nearly obscured) it was sent to pull out, both of which fell through lake ice that was not thick enough to support them. Unfortunately, events like this occur every year, sometimes with loss of life. We offer here some guidelines for determining the safety of freshwater ice.

Background

Because vehicles, snowmobiles, and people often have fallen through ice, research has been done to determine when an ice sheet is safe for certain loads. Gold (1971) collected a considerable amount of data on the use of ice sheets by aircraft, construction activities, trucks, and tractors in Canada. Using these observations, Gold proposed three plots to represent safe ice thicknesses for various loads (Fig. 2). The upper plot is the most conservative (i.e., safest), while the lower plot is the least conservative.

Gerard (1986) described the behavior of an ice sheet under load, including moving loads. He explained that an ice sheet must deform into a bowl shape when loaded, to increase the hydrostatic pressure on the bottom of the ice sheet and thereby balance the load.

Another analysis of the bearing capacity of an ice sheet is given in the Engineer Manual *Ice Engineering*, EM 1110-2-1612 (U.S. Army 1982). This manual contains information similar to that presented in this bulletin, and also includes information on the creep of an ice sheet for loads of long duration. A figure in the manual is similar to the loaded block of ice shown in Figure 3. This figure shows that the unloaded freeboard, $h - Z_0$, decreases to $h - Z_L$ when the ice is loaded, such as by a vehicle, and also shows that the increased buoyancy force acting upward at the bottom of the ice equals the weight of the vehicle, P.

What you need to know

Because there can be many variations in the structure, thickness, temperature, and strength of an ice sheet, it is essential to carry out some fairly simple field observations of the ice sheet you want to use to support a load. Be cautious! Never go out on an unknown ice sheet alone, and always probe ahead of yourself with a heavy ice chisel. Consider wearing a personal flotation device and roping yourself to an assistant.

The main thing to determine is the ice thickness. This can be done by drilling holes with an ice auger. Note whether the ice is clear (sometimes called "black ice") or white (due to air bubbles—sometimes called "snow ice"). Measure the thickness of both kinds. Take note of the frequency of cracks and whether they are wet or dry. On rivers, be alert to variations in ice thickness that may occur as a result of bends, riffles or shallows, junctions with tributaries, etc.

For both rivers and lakes, warm inflows from springs may create areas

Figure 1. Vehicles that have broken through a lake ice cover. (Photo by Vyto Starinskas, Rutland Herald, *Rutland, Vermont; used by permission.)*

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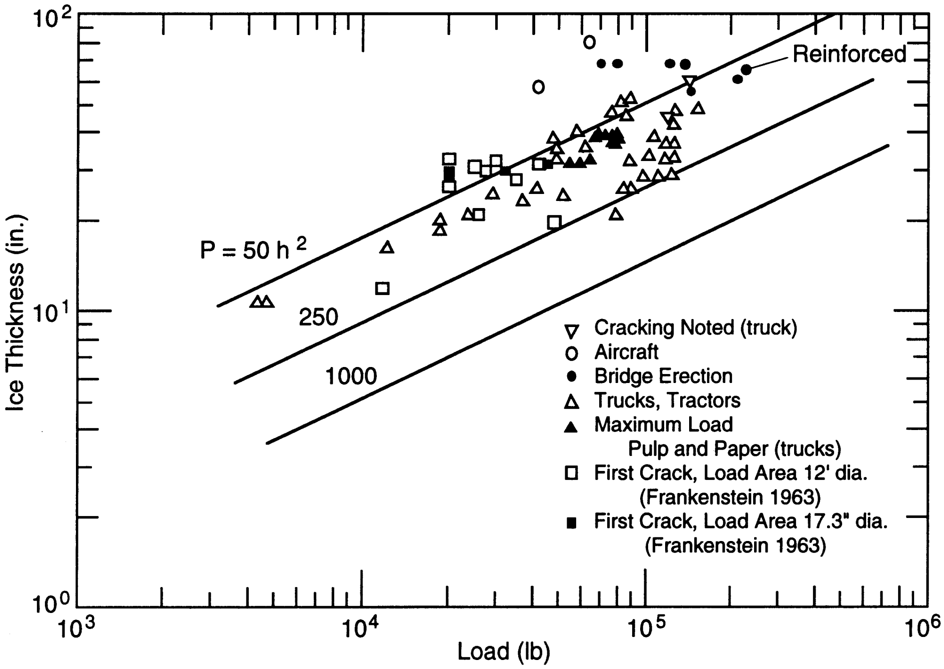

Figure 2. Canadian field data on safe ice thicknesses for various loads. (After Gold 1971.)

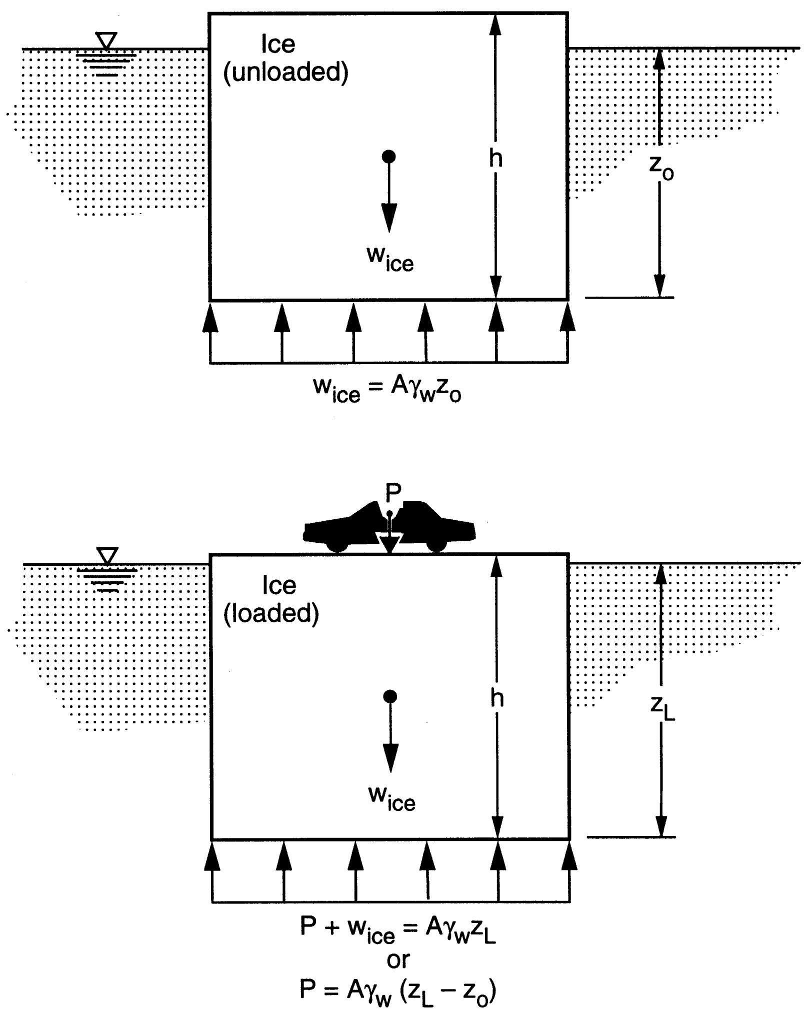

Figure 3. Forces acting on unloaded and loaded ice blocks.

of thinner ice. Also, the ice thickness near shore may be thinner (due to warm groundwater inflow or the insulating effect of drifted snow) or thicker (due to the candle-dipping effect of variable water levels).

Observe any snow cover as well as variations in its thickness. Obtain the record of air temperature for the past several days, and continue observing air temperatures during the period the ice will be used to support loads.

Required minimum ice thickness

A simple formula, used for decades to estimate the minimum ice thickness required to support a load, is

$$h = 4(P)^{1/2}$$

where h is the ice thickness in inches and P is the load, or gross weight, in tons. A plot of this equation is given in Figure 4. This equation can also be expressed by Table 1, in which the vehicle class equals the *total* load in tons (not the vehicle's load capacity).

The third column, distance between vehicles, is about 100 times the ice thickness, and is the safe distance to keep between loads at the required minimum ice thickness. At thicknesses greater than the minimum ice thickness, this spacing can be reduced.

When driving a vehicle on an ice sheet, a recommended procedure is to drill a hole and check the ice thickness at intervals along the intended path. This should be done every 150 feet, or more frequently if you discover that the ice thickness is quite variable.

There are several additional points to consider. First, the formula and the table assume clear, sound ice. If white, bubble-filled ice makes up part of the ice thickness, count it as only half as much clear ice. For example, if you encounter eight inches of ice made up of four inches of white ice on top of four inches of clear ice, the white ice should be considered equal to only two inches of clear ice. Therefore, this ice sheet (two inches equivalent clear

ice plus four inches actual clear ice) is the same as a six-inch ice cover for the purposes of determining the load it can support.

If there has been a recent large snowstorm, the snow represents a new load on the ice. If the new snow is sufficiently heavy, it will depress the ice and allow the ice sheet's top surface to be submerged below water level. Water then will seep through cracks to flood the ice surface and saturate the lower layers of the snow. Until this slush completely freezes, stay off the ice sheet. When the saturated snow freezes, it becomes an added thickness of white ice.

Contrary to what many think, a rapid and large air temperature *drop* causes an ice sheet to become brittle, **and the ice may not be safe to use for 24 hours**. If the air temperature has been *above* freezing for at least six of the previous 24 hours, multiply the vehicle class by 1.3 (as shown by the lower dashed line in Figure 4) to obtain a larger minimum ice thickness, accounting for possible weakening.

If the air temperature stays above freezing for 24 hours or more, the ice begins to lose strength, and the table no longer represents safe conditions. This becomes the general condition in the spring. Even though the ice may have adequate thickness, the strength is quickly lost the longer the air temperature is above freezing. In all cases of air temperature changes, the effects are greatest on bare ice, and are subdued by increasing depths of snow cover. However, no quantitative guidance can be offered.

If a vehicle is parked on the ice for more than two hours, multiply the vehicle class by 2 (shown by the upper dashed line in Figure 4) to obtain the required minimum ice thickness. An ice sheet will creep, or deform, over a long period of time, without any additional load. Therefore, if an ice sheet has to be loaded for a long period, a recommended field procedure is to drill a hole near the load and check the freeboard, as shown in Figure 5. If the water begins to flood the ice, move the load immediately. Remember this ice behavior if your vehicle becomes disabled. If left for a few days, it may break through the ice as a result of long-term creep.

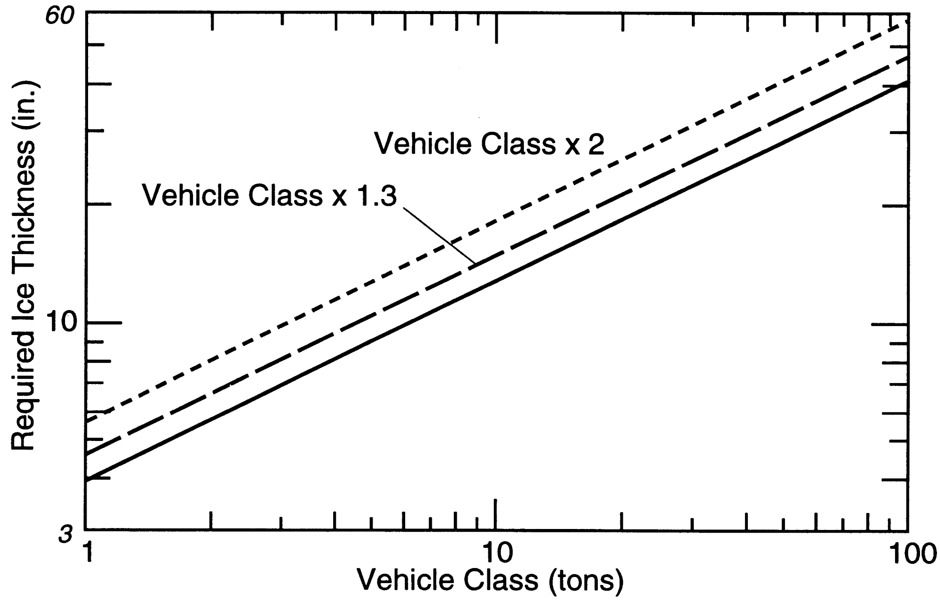

Figure 4. Required minimum ice thicknesses for given total loads (expressed as vehicle class; equivalent to gross vehicle load in tons). See discussion in text before using.

Table 1. Minimum ice thickness required to support a load.

Vehicle Class (tons)	*Required Ice Thickness (inches)*	*Distance Between Vehicles (feet)*
0.1	2	17
1	4	34
2	6	48
3	7	58
4	8	67
5	9	75
10	13	106
20	18	149
30	22	183
40	26	211

Roads on ice

Because they can represent considerably reduced driving distances, ice sheets are often used for roads across lakes. Ice bridges are used to cross rivers when ferries can no longer operate. Usually snow is plowed off of the path chosen for the road. Removing the snow enables the ice to grow faster and increases the bearing capacity. Remember, though, that plowed snowbanks represent concentrated loads on the ice. They should be spread over as large an area as possible.

Another way to increase ice thickness is to flood the ice by pumping water onto it. This is usually done in several floodings over a period of days, allowing each flooding to freeze before the next is applied. The snow is usually removed for a distance much

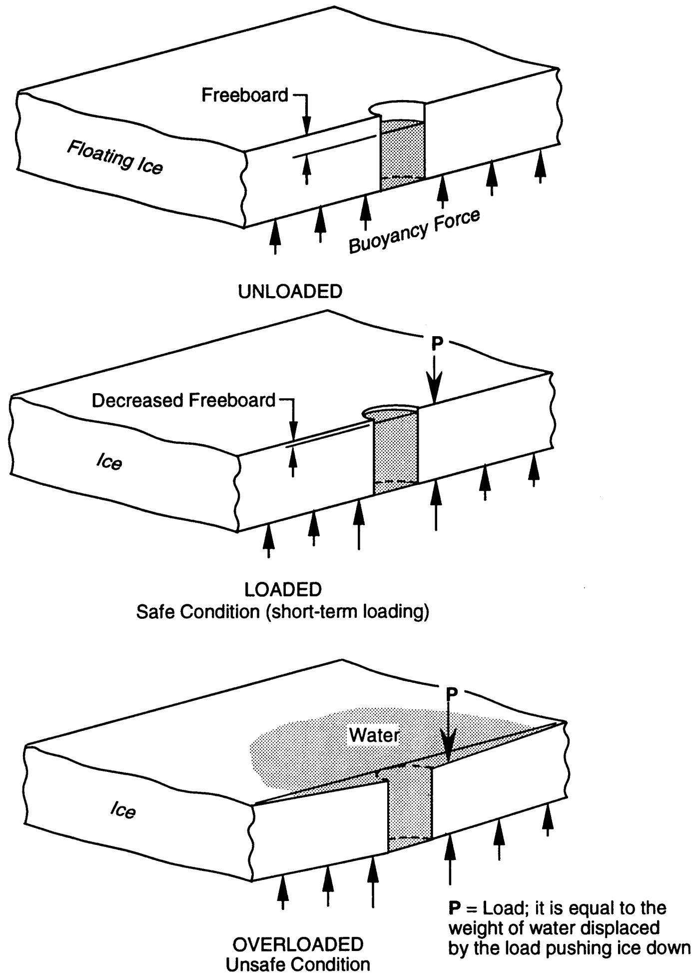

Figure 5. Unloaded and loaded ice sheet, and flooding of the ice surface when overloaded.

wider than the road itself. Repeated travel on an ice road may fatigue the ice, and so it is common practice to move the path between two destinations periodically (e.g., every week).

When driving on floating ice, the deflection bowl moves with the vehicle, generating waves in the water. If the speed of these waves is the same as the vehicle speed, the deflection of the ice sheet is increased and will likely lead to failure of the ice. This is known as the critical velocity, and is discussed by Gerard (1986). The problem is more serious for thin ice and shallow water depths. When in doubt, drive below 15 mph.

Other considerations

An ice sheet must be supported by water. Sometimes, near a riverbank, the water level will drop after the initial ice sheet is formed, leaving the ice sheet unsupported near the shore. This occurrence can be detected by hearing a hollow sound when probing with an ice chisel. Naturally this is not a safe location for loads on the ice.

Cracks in the ice are either wet or dry. If dry, they do not penetrate the ice sheet and are not a problem. If they are wet, multiply the vehicle class by 2, as shown in Figure 4, to obtain the required minimum ice thickness. Also, drive across the cracks as close to perpendicular as possible, instead of parallel to them.

On thicker ice with very heavy loads, radial cracks may be observed originating from the center of the load. This usually occurs at about one-half of the failure load. After the radial cracks develop, circumferential cracks will form and the ice sheet will fail. If radial cracks are seen, the load should be moved immediately. Because ice will creep, it is only a matter of time before the ice fails. The same process happens with thinner ice at breakthrough loading, but the process occurs so much faster that it cannot be relied upon for any warning.

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